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INDOOR ENVIRONMENT AND ENERGY CONSUMPTION IN DWELLINGS BEFORE AND AFTER REFURBISHMENT IN SLOVAKIA

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ABSTRACT

Indoor built environment, e.g. thermal environment and indoor air quality, is most important parameter related to the energy conservations activities in dwelling buildings in cold climate. Most of the dwelling buildings in Slovakia built last 50 years do not satisfy the current requirements for energy efficiency. Energy saving measures for building constructions and HVAC-systems are taken to improve the energy efficiency of these buildings and reduce their energy consumption. Impact of these measures on the indoor built environment is rarely considered, they often compromise thermal comfort to the operation of heating systems and/or indoor air quality due to the decreasing ventilation and infiltration rate. Also poor indoor built environment in dwellings my have adverse effect on the health and comfort of the occupants. The objective of the study was to evaluate the impact of the refurbishment on the indoor built environment and energy consumption. Thermal comfort and indoor air quality were taken into consideration based on objective and subjective evaluations. It was done in couples of identical dwellings, before and after their refurbishment. Besides the recording of the energy consumption for heating also the monitoring of the thermal comfort and indoor air quality parameters had been done. Results show us very good correlation between energy consumption for heating and as well as between indoor air change rate.

INTRODUCTION

Buildings are responsible for a substantial portion of global energy consumption. Residential buildings constitute the largest part of the building stock, with 75% by floor space within the European Union [1]. They are responsible for the majority of energy consumption in energy sector. In 2009, European households were responsible for 68% of the total final energy use in buildings. The dominant energy end-use in homes is space heating. It is shown year-to-year fluctuations in heating consumption largely depend on the climate of a particular year [2].
According to Jurelionis et al. Most of the European countries obtained a large housing stock since the 1950's due to consequences of the war, economic changes and fast growing population. Majority of these residential buildings, especially in Central Europe were built from prefabricated concrete blocks. They consume more than one third of the final energy consumption. Due to poor maintenance,

their renovation became one of the most important measures addressing energy conservation in these countries. Energy renovation is an important topic not only on field of energy conservation. It may influence the quality of life as well. People spend more than 90% their time indoors, with a significant portion of this time spent at home [4]. This is the main reason why the potentially impact of these measures on indoor environmental quality should not be negligible, especially in countries where the trend is to put efforts into air infiltration losses by envelope insulation and tight plastic windows. It is unclear how such changes influence indoor environmental quality. Changes can be negative or positive, and some measures will not influence indoor environmental quality at all [5] [6].
Slovakia well represents the residential building stock of Central Europe. It has 341,000,000 m² of building floor area, out of which 88% (300,080,000 m²) are located in residential buildings [1]. Most of the dwellings were built from 1948 to 1990, with the highest intensity in housing construction reported over the period 1971 –1980. Majority of these multifamily residential buildings do not satisfy the current European requirements on energy efficiency. Nationwide remedial measures are taken to improve the energy efficiency of residential buildings and reduce their energy consumption [8].
The current study investigates the impact of energy renovation on thermal comfort and indoor air quality of apartment buildings during winter months. It also provides picture of the recent state of energy consumption and indoor environmental quality of the Slovak residential stock.

METHODOLOGY OF INDOOR ENVIRONMENT AND ENERGY EFFICIENCY MEASUREMENTS

Thermal comfort

Six pairs of residential buildings were chosen for the energy and thermal comfort analysis. Each pair of dwellings contained from identical apartment buildings in term of construction systems. The following Slovak structural systems were chosen: TA 06 BA, BA NKS, ZTB, BA NKS P.1.15, P.1.14, P.1.15. In each pair of buildings one dwelling has been recently renovated (thermally insulated façade, replacement of old windows for new energy efficiency windows, hydraulic balancing of the heating system, manual control of heaters, insulation of main branches of pipes of heating and water system), while the other one is in its original condition.

Objective measuremtns

The investigated residential buildings are located in capital of Slovakia [9].
The investigation of indoor environment was carried out in three pairs of dwellings located on southwest part of Slovakia, 20 km from capital. The selection of the dwellings was based on the same method as in the study of energy performance and thermal environment by Pustayová [9]. One of the buildings in each pair of dwellings has been renovated (thermally insulated façade, replacement of old windows for new energy efficiency windows, hydraulic balancing of the heating system) and the other was in its original state. Natural ventilation was used in all buildings. Exhaust ventilation was present in bathrooms and toilets [11].
Energy audit was carried out to investigate the energy performance of residential buildings. It included inspection, evaluation and analysis of existing situation of the selected buildings. Energy need for heating was calculated for each investigated dwelling. Also the real data of energy consumptions were collected from housing associations maintaining selected residential buildings. The detailed steps of energy auditing are shown in publication by Dahlsveen et al [10].

Indoor Air Quality

Building description

The residential building investigated (Fig. 1.) is located in Šamorín, Slovakia. It was built in 1964 from lightweight concrete panels. The building was naturally ventilated. Exhaust ventilation was only used in sanitary rooms, such as the bathrooms and toilets. Renovation of the building was carried out in 2015 and included the following measures: insulation of the building envelope using polyethylene (80 mm), insulation of the roof using mineral wool (120 mm) and hydraulic balancing of the heating system. New plastic frame windows had already been installed in recent over the last years in most of the apartments in the building. [12]

Figure 1. Residential building before and after renovation

Table 1. Heat transfer coefficients of constructions before and after renovation

Structure	Heat transfer coefficient Non renovated building **Ui [W/(m²K)]**	Heat transfer coefficient Renovated building **Ui [W/(m²K)]**	Area **SUM Ai [m²]**	Average heat transfer coefficient Non renovated building **Ui [W/(m²K)]**	Average heat transfer coefficient Renovated building **Ui [W/(m²K)]**	Improvement of the heat transfer coefficient (%)
External wall 1	**1,6**	**0,37**	1766,85	**1,49**	**0,35**	**76,50%**
External wall 2	**1,59**	**0,36**				
External wall 3	**0,49**	**0,23**				
External wall 4	**0,44**	**0,23**				
Wall of the machine room	**1,69**	**0,38**				
Flat roof	**0,8**	**0,22**	328,77	**1,23**	**0,23**	**81,30%**
Flat roof of the machine room	**1,93**	**0,27**				
Ceiling above the basement	**0,88**	**0,33**	338,77	**0,88**	**0,34**	**61,40%**
Transparent structures	**1,56**	**1,3**	569,43	**1,56**	**1,3**	**16,70%**
			3013,82	**1,439**	**0,544**	

Objective measurements methodology

The first round of the measurements was performed in January 2015 when the building was still in its original condition, and the second round was performed in January 2016 after energy saving-measures had been implemented. Twenty apartments were selected across the residential building; they were equally distributed on the lower, middle and highest storeys of the building. The same apartments were investigated in both winter seasons over a period of eight days [13] [14]. The temperature, relative humidity and CO2 concentration were measured in the bedrooms of the apartments. HOBO U12-012 data loggers and CARBOCAP CO2 monitors (Figure 3) were used for recording the temperature and CO2 concentration data.

RESULTS AND DISCUSSION

Results of thermal comfort and energy efficiency

Energy evaluation

The energy need for heating was calculated for each pair of residential buildings by Pustayová [9]. As it is shown in Table 1 energy save potential was higher than 30% in case of all pairs of dwellings. The highest percentage of energy save potential between original and renovated building was found for dwellings built in structural system T06 BA (52%). According to Slovak regulations each building was categorized into energy classes based on calculations mentioned above. As results show renovated buildings were classified into higher energy classes than original buildings.

The real data of energy consumption show almost the same results than the results from calculation. Visible differences could be recognized only in case of structural systems ZTB and BA NKS-S P.1.15. The real energy consumption (15%) in case of ZTB residential buildings was lower by 36% than the calculated value (51%). Real energy savings (28%) of dwellings with structural system BA NKS-S P.1.15. were also lower by 12% than the calculated one (40%). Noticeable difference between the investigated relation of calculated and real values might be caused by standardized climatic conditions for Bratislava which were used in calculation method. The real conditions are usually different from the standardized ones. In this case of study the real outdoor temperature was changing day to day during the heating season.

Table 2. Summary of real energy consumption, energy calculation and energy classification of residential buildings

Structural system	State of building	Real energy consumption (kWh)	Difference (%)	Energy need for heating (kWh)	Difference (%)	Floor area (m^2)	Energy class for heating
T06 BA	Original	307433	55	352148	52	3723	D
	Renovated	138889		169846			B
BA NKS	Original	388956	39	368329	34	3980	D
	Renovated	238703		241607			C
ZTB	Original	722910	15	843437	51	9094	D
	Renovated	611930		409814			B
BA NKS S P.1.15	Original	476440	28	530000	40	6110	D
	Renovated	341469		319871			B
P.1.14	Original	367970	43	360571	38	4680	C
	Renovated	209278		224244			B
P.1.15	Original	239192	51	343533	51	3421	D
	Renovated	117890		181263			B

Thermal environment

The following results present the outcomes of the comfort survey based on occupants´ subjective evaluation. The survey was performed in the same dwellings where the energy consumption was investigated. Figure 1 shows summary of occupants´ answer regarding their thermal sensation (a) and acceptability (b) of thermal environment. The average thermal sensation evaluated by occupants of original buildings was 0.78, what indicates to almost slightly warm thermal environment. In case of the renovated dwellings occupants evaluated the thermal environment warmer than residents in the original ones. According to answers from questionnaires filled in the retrofitted buildings the average thermal sensation was 1.36 (between slightly warm and warm). The occupants were also asked about what type of thermal sensation they would prefer according to 7-points ASHRAE scale. Answers of occupants were almost the same in both types of dwellings – in the original buildings they would prefer thermal sensation with average 1.23 and in the retrofitted ones the ideal average thermal sensation would be 1.28. The answers of occupants present that it does not matter if the dwellings is in its original or renovated condition they would prefer similar conditions of thermal environment in both types of buildings. Acceptability of thermal environment was evaluated by scale of acceptability mentioned above, in methodology section. Residents of renovated buildings indicated to more acceptable thermal environments (0.56) than occupants of original buildings (0.3).

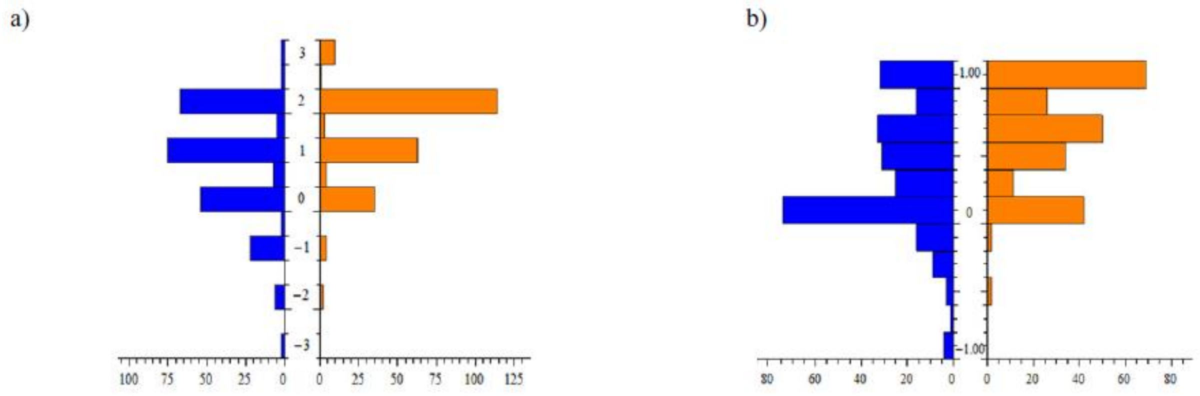

Figure. 2. Thermal sensation (a) and acceptability of thermal environment (b) evaluated by occupants of original (blue bars) and retrofitted (orange bars) residential buildings.

Results of thermal comfort and energy efficiency

Energy evaluation

The heat demand was calculated for the non renovated and renovated condition. The highest energy-saving is provided by the thermal insulation of the external walls. This can be explained with the large heat exchange surface of the walls. On the Figure 3. is clearly indicated the heat demand for the structures for square meter and the solar and heat gains for both types of residential building. The figure shows that the heat demand for the insulated part of the building significantly decreased and for the calculated air exchange rate (AER) and gains remained the same.

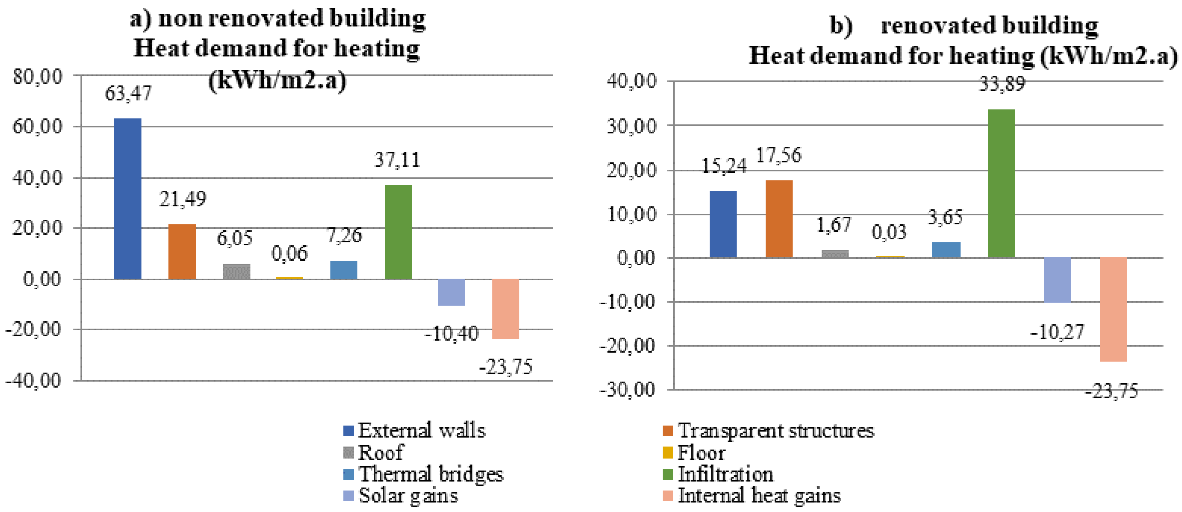

Fig. 3. Heat demand of the building (a- non renovated, b-renovated)

The renovated and non renovated residential building were classified into energy classes by the valid Slovak legislation: Decree of the Ministry of Construction and Regional Development No:300/2012.

The energy-saving measures mentioned above decreased the energy consumption by 55%. In accordance to our law on energy efficiency of buildings, the original dwelling belonged to the „E“ category (159 kWh/m^{2}a), after refurbishment to the „B“ category (74 kWh/m^{2}a).

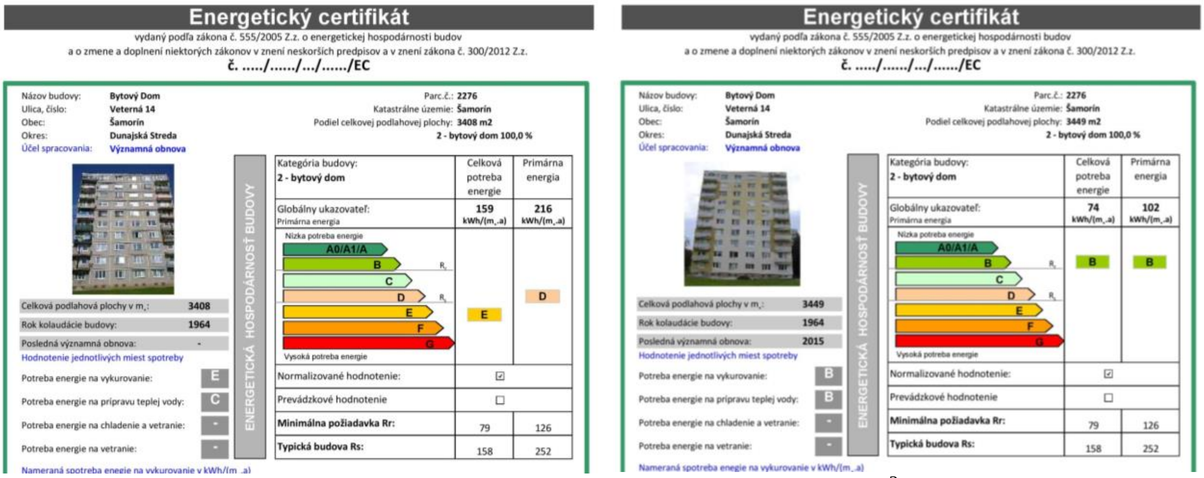

Figure. 6. Energy performance certificate of the building before (left) and after (right) renovation.

Indoor environment evaluation

From the measured data is obvious that day and night average temperature was higher in the renovated building than in the non renovated (Figure 4 (right) , Table 3).

Table 3. Indoor air temperature before and after renovation [15] [16]

a) Before renovation (N=20)

Time period	T (°C)		
	Average	Minimum	Maximum
Day	20,7	20,1	23,6
Night	21,2	18,8	24,2
Whole period	20,9	18,7	23,9

b) After renovation (N=20)

Time period	T (°C)		
	Average	Minimum	Average
Day	22,1	20,1	23,9
Night	22,4	20,8	24,0
Whole period	22,2	20,6	24,0

The relative humidity was very similar in both types of residential building (Figure 4 (left), Table 4).

Table 4. Relative humidity before and after renovation [15] [16]

a) Before renovation (N=20)

Time period	RH (%)		
	Average	Minimum	Maximum
Day	46,1	34,8	59,1
Night	47,1	34,8	63,0
Whole period	46,2	34,5	60,8

b) After renovation (N=20)

Time period	RH (%)		
	Average	Minimum	Maximum
Day	47,3	38,3	58,4
Night	48,8	38,9	59,9
Whole period	47,9	38,6	59,1

Both measured values fulfils the requirement of the Slovak standard STN EN 15 251(T: T>20°C; T<24°C; RH: RH>30%; RH<70%)

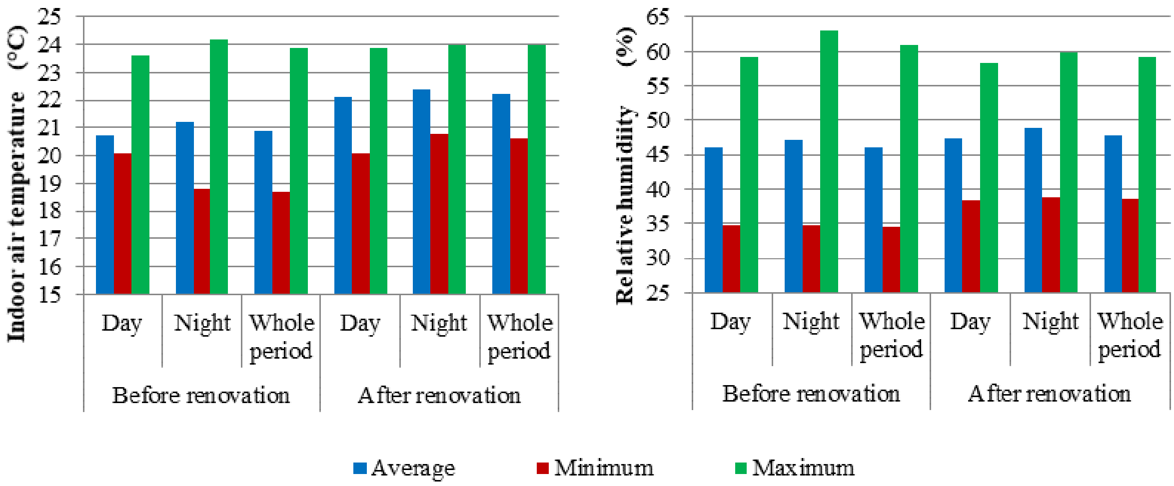

Fig. 4. Average temperatures (left) and relative humidity (right) in the apartments before and after complex renovation [16]

The CO2 concentrations before and after the renovation of the building are shown in Figure 5. Most of the CO2 concentration data points were within the acceptable limit (green line) before the renovation (blue line), while significantly higher concentrations were measured after the renovation (red line). Table 5 and Figure 6 present the descriptive statistics of the day and night-time CO2 concentrations before and after the renovation of the residential building. The grand average was 1205 ppm, and the median was 1190 ppm before the renovation.

After implementing the energy-saving measures, the CO2 concentration visibly increased. The mean was 1570 ppm, and the median was 1510 ppm. Table 5 shows the percentages of the average day and night-time CO2 concentrations above four cut-off values in the residential building before and after its renovation. A higher number of the apartments exceeded 1500 ppm and the upper concentrations during both the day and night-time after the renovation than before the renovation.

The lower CO2 concentration before the renovation resulted in higher AERs in the apartments (average 0.61 h-1). After the renovation, the mean air exchange rate (0.44 h-1) dropped below the recommended minimum (0.5 h-1) (Table 7 and Figure 7).

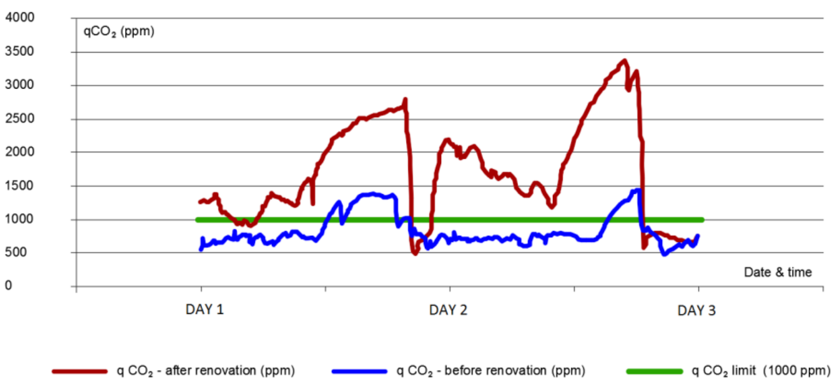

Figure 5. Example of CO2 concentration in one selected apartment during two days out of the whole measurement period before and after the renovation. [15] [16]

Table 5. Day- and night-time CO2 concentrations before and after renovation of the residential building. [15] [16]

a) Before renovation (N=20)

Time period	CO_2 (ppm)			
	Average	Minimum	Maximum	Median
Day	1040	595	1550	1030
Night	1400	740	2665	1300
Whole period	1205	660	2050	1190

b) After renovation (N=20)

Time period	CO_2 (ppm)			
	Average	Minimum	Maximum	Median
Day	1320	790	2210	1265
Night	1925	865	3575	1825
Whole period	1570	870	2770	1510

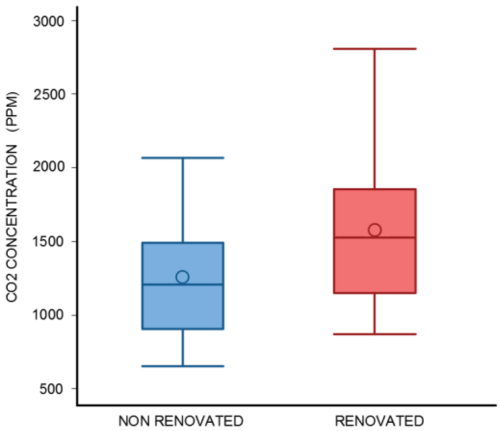

Figure 6. CO2 concentration before and after renovation as a statistical output [15] [16]

Table 6. The fractions of the apartments where the average CO2 concentration exceeded 1000, 1500, 2000 and 2500 ppm during the day- and night-time. [15] [16]

a) Before renovation (N=20)

Time period	Cut-off values [%]			
	CO_2>1000 (ppm)	CO_2>1500 (ppm)	CO_2>2000 (ppm)	CO_2>2500 (ppm)
Day	60	10	0	0
Night	75	40	10	5

b) After renovation (N=20)

Time period	Cut-off values [%]			
	CO_2>1000 (ppm)	CO_2>1500 (ppm)	CO_2>2000 (ppm)	CO_2>2500 (ppm)
Day	75	30	10	0
Night	95	70	40	15

Table 7. AER before and after renovation [15] [16]

AER	Average	Minimum	Maximum	Median
Before renovation (N=20)	0.61	0.32	1.15	0.59
After renovation (N=20)	0.44	0.21	0.76	0.45

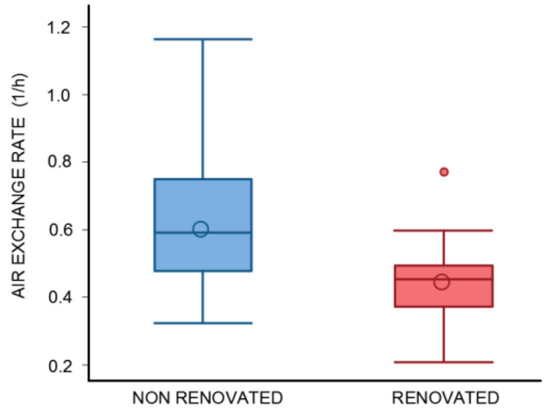

Figure 7. Air exchange rate before and after renovation as a statistical output [15] [16]

CONCLUSION

The conclusion is based on data processed from field studies of energy consumption, thermal comfort and indoor air quality. Analysis shows that energy performance of the investigated buildings has been improved after implemented of energy saving measures and the retrofitted buildings could be classified at least by two classes higher than non-renovated residential buildings. It is well known, that thermal comfort is one of the main compwhat may affect energy consumption directly. It has been found that people prefer higher temperature indoors, especially in case of non-renovated buildings. Most of the occupants reported overall comfort level of thermal environment as acceptable. Analysis of dependence of indoor air quality on renovation shows negative influence on indoor air quality. As the results of CO2 concentration and perceived air quality show renovation of apartment buildings in Slovakia may reduce the quality of indoor air in the apartments. The average concentration of CO2 is visible higher in renovated buildings and it does not fulfil the criteria of 1000 ppm. Energy renovation of buildings should be included renovation of ventilation system as well. Without installing mechanical ventilation the only way to control the air change rates and get better indoor air quality is ventilate more often after renovation while the building is in its original condition.

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BIOGRAPHY

Professor Dušan Petráš from Slovak University of Technology in Bratislava-Slovakia, is the former vice-rector of STU and dean of the Faculty of Civil Engineering. Also, he is the president of Slovakian HVAC-Association SSTP (Slovak Society of Environmental Technology) and the past-president REHVA (Representative European Heating, Ventilation Association). In the present he is the professor at the Department of Building services and dealing with the HVAC-systems in buildings.

His scientific work is focused on the energy conservation by performance of the buildings with respect to the providing the health and comfortable indoor environment. He is author and coauthor of 15 books (Energy auditing of Buildings, Renewable Energy Sources for Low-temperature systems, Low-temperature heating and High-temperature cooling...), 50 scientific papers in foreign journals/on international conferences as well as about 100 lectures in 25 countries in 3 world languages.

Professor Petráš is also member of AEE, ASHRAE, Academy of ISIAQ, REHVA Fellow, he was also the Guest Professor in DTU Lyngby (Denmark) and Guest Lecturer in FH Pinkafeld (Austria).